

Development of a broadband achromatic Twyman-Green interferometer

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ABSTRACT

A modified Twyman-Green interferometer is in use that makes possible wavefront testing of optical filters at any wavelength from 200 to 1100 nanometers. The use of mirrors for collimation and pupil imaging makes the instrument achromatic, and therefore the focus is fixed over the entire bandwidth. The beamsplitter and compensator plates are made of fused silica, and the detector is a UV enhanced CCD camera. A tunable monochromator with a broadband light source permits selection of any wavelength. Fringe distortion, even when the collimating mirror is spherical, is small enough to keep measurement errors within 0.1 wave peak to valley over the 2 by 2 inch aperture.

1. INTRODUCTION

Most optical filters made today are not intended for use in imaging systems where wavefront errors are of concern, and they generally show themselves as unsuitable for such applications. (Figure 1) But many users are now asking for "optical quality" filters and finding that the ability to test them is rare.

The Jet Propulsion Laboratory has procured sets of filters for the Wide Field/Planetary Camera, one of the primary instruments for the Space Telescope. The need to measure the transmitted wavefront of numerous broadband and narrowband filters has led to the development of a modified Twyman-Green (T-G) interferometer. In the past this need has been partially met by use of a classical T-G interferometer¹ which was limited in bandwidth to the 400-700nm region. It was also awkward to use because the focus shifted with changing wavelength causing the interference fringe contrast to decrease. In addition a darkened room and a relatively large vibration isolation table were required.

The goal was to design an instrument which would:

- 1) extend the band to 200-1100nm,
- 2) have a clear aperture of at least 2 inches square,
- 3) be convenient to use, relatively insensitive to vibration, and portable.
- 4) operate in normal room light.

The challenges expected included:

UV sensitivity--A combination of detector, monochromator, and light source would have to be found or developed.

Dynamic range--Optical filters generally transmit from 10 to 70 percent at their peak and may have bandwidths varying from a few Angstroms to hundreds of nanometers. What effect would these variables have on fringe visibility? Would several beamsplitters be required, each with a different coating, so that beam intensities can be balanced?

Portability/Stability--It was highly desirable to be able to transport and use this instrument without special facilities and complex realignment.

Ease of Use--It can be time consuming to search for the proper fringe pattern when a light source is to be used that has a coherence path length of only a few microns. Could an instrument be built which would offer convenience and

simplicity and require a minimum amount of training and experience?

This paper describes the general design of the interferometer and includes experimental data and results.

2. APPROACH

The very broad spectral requirement dictated the use of mirrors rather than lenses. A lens system designed for broadband would require glasses which would not transmit down to 200 nm. In addition, in a reflective system, to avoid an obscured collimator, an off-axis configuration would be necessary. A parabolic surface would do the job, and normally two such mirrors would be required -- one to collimate the source and the other to decollimate or image the source. Off-axis parabolic mirrors are expensive. Could the mirrors be spherical? And could the same mirror serve as collimator and imager? Should the last two questions be answered yes then the significance would be reflected in the instrument's cost and compactness. The design was drawn up to use a single spherical mirror to replace the two lenses used in the traditional approach. Figure 2 is a schematic of the two systems.

If the optical path lengths for both arms were precisely equal then the aberrations introduced by the spherical mirror would be identical in both arms and effectively cancel. The fringe pattern would then accurately represent only the difference between the two wavefronts. Lateral shearing is minimized by proper alignment of the instrument and tilting of the reference flat.² The equality of arms is assured by the very short coherence length of the light source.

The bandwidth may be extended to 1100 nm quite easily by using a silicon based CCD as the detector. Conventional optics and light sources generally function at wavelengths up to the near IR. The UV end, however, would require special attention. The low end cut-off for typical CCDs is about 400 nm. To extend sensitivity the CCD was coated with a fluorescent material in much the same way as the CCDs were for the Wide Field/Planetary Camera. This coating converts UV to visible and functions from 400 nm to 200 nm and beyond while maintaining its transparency in the longer wavelengths.

For the transmission optics fused silica seemed an obvious choice. It is thermally stable, available with excellent homogeneity, and the transmission at 200 nm is still above 85% for a thickness of 30 mm. The beamsplitter and compensator plates are made of this material, as is the field lens. The beamsplitter coating is a thin layer of aluminum deposited to transmit about 50% and reflect 20% (The filter being tested is always inserted in the "through" arm of the interferometer).

The monochromator is a miniature Fastie-Ebert type which covered the spectral region of interest. Two light sources are used, a quartz lamp for 400 nm to 1100 nm and a filtered xenon arc to provide the near UV. A deuterium source may be desirable to provide enough energy at 200 nm without using a high powered xenon lamp.

3. EXPERIMENTATION

Optics Configuration

We had confidence that the fringes would be straight, etc; the real concern was gross distortion of the test field (pupil). Using a spherical mirror off-center was unusual for any kind of imaging. First attempts looked good by eye. To measure distortion more precisely a target mask (Figure 3) was placed in the test field and its image evaluated. This was first tried using a field lens (quartz) and then later a field mirror. The image of the plate (Figure 4) illustrates that distortion is negligible with the lens but significant with the mirror. The mirror has the advantage of eliminating axial color and therefore the need to refocus. The spherical field mirror worked better the closer it came to operating on center. An aspheric would probably be superior. The focal length of the field lens or mirror was used to vary the size of the interference pattern on the television monitor. A shorter focal length would be desirable if a brighter image were required. Fringe contrast across the pupil decreased where distortion was largest. It also decreased as the source size was increased.

A comparison was made between our T-G and a Zygo Fizeau interferometer. The test piece was a high quality quartz window with slight power. The two interferograms make up Figure 5.

CCD camera

A Sony CCD b&w camera was used because it was small, had a removable lens, and we owned one. The windows were removed and a fluorescent material was vacuum deposited on two-thirds of the detector surface. A test was run to determine qualitatively the effectiveness of the coating. A monochromator with a deuterium source illuminated the CCD from a distance of a few inches as the wavelength was changed. A third of the CCL) was masked to provide a zero level comparison. The uncoated area cut off at about 360 nm, the coated area at 195 nm. The UV end was likely attenuated by the room atmosphere. It appeared that if sufficient light were available 200 nm would be achievable as a lower limit test wavelength in our Twyman-Green.

4. ANALYSIS

The principal optical feature of this interferometer in comparison with the classical T-G is the decentered and tilted spherical mirror. While the effect of the aberrated wavefront, as described above, is canceled so far as the interference is concerned, still there is the question of whether distortion of fringe location might be introduced when imaging the testing fringes onto the detector.

The fringe pattern formed at the beam splitter is imaged by the tilted and decentered spherical mirror and relayed by the field lens to the CCD. To calculate distortion, just one arm of the interferometer needs to be considered. The stop is at the spherical mirror. The chief rays, which determine the distortion, are parallel to the optical axis in object-space and are focused at the center of the field lens by the spherical mirror. Distortion can be obtained by real-ray tracing and by locating the centroid of each chief ray in the image plane. The deviation of each centroid from that of the corresponding paraxial ray is the distortion. Code V gives its peak magnitude as 3% across the 2.25 inch field.

5. FINAL CONFIGURATION

The interferometer is 28 by 16 by 7 inches high. The light source and tv monitor are separate. It weighs 40 pounds, is rigid and enclosed so that it may be used on an ordinary desk or table with the room lights on. A two wheel filter assembly has been added to provide greater control over the light source intensity and spectral bandpass. The monochromator grating was chosen to take advantage of multiple orders to cover the full range of wavelengths. A quartz field lens is used to minimize distortion. It is mounted on a rod assembly which permits easy focusing and rotates out of the beam for co-alignment of the two arms. Tilt control is accomplished with the reference flat mirror. The test arm's length is adjusted using a digital micrometer.

6. CONCLUSION

The Broadband Achromatic Twyman-Green (BAT) Interferometer has proven to be effective for wavefront testing of a wide variety of optical filters. It has a useful bandwidth from 200 to 1100 nanometers, is convenient to use, compact, and accurate. The use of a single spherical mirror for both collimator and imager is viable. Fringe contrast varies widely because of beam intensity mismatch but is generally adequate with just a single beamsplitter. The experimental results and the theoretical analysis are in good agreement. Figure 6 is a series of interferograms taken at a variety of wavelengths.

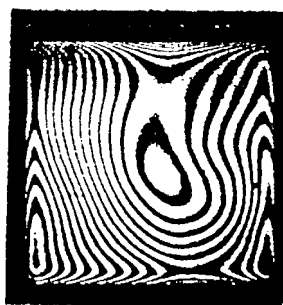
7. ACKNOWLEDGMENTS

The work described in this paper was performed while the authors were at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.

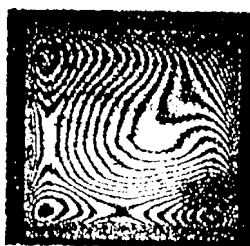
The authors thank K. LaBau, D. Thicssen, and J. Voeltz for their hardware efforts; J. Brunachc for optics; D. Preston for technical discussions and support of the optical design analysis; and T. Reilly for his encouragement.

8. REFERENCES

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2. 'I'. Pope, and R. Zieliński, Applied Optics, Vol 19, No.20, pp 3422-3, 15 Oct 1980.

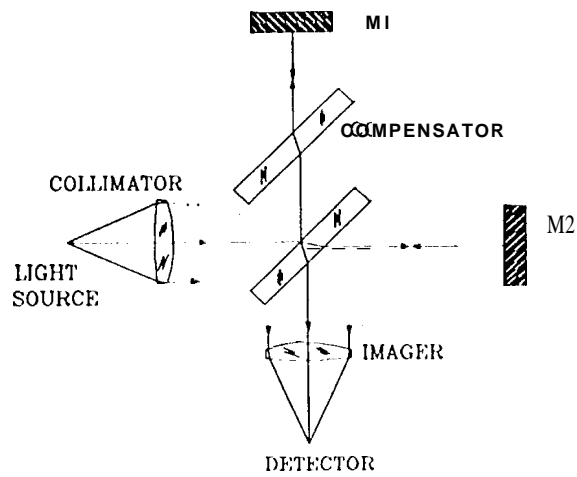


500 nm

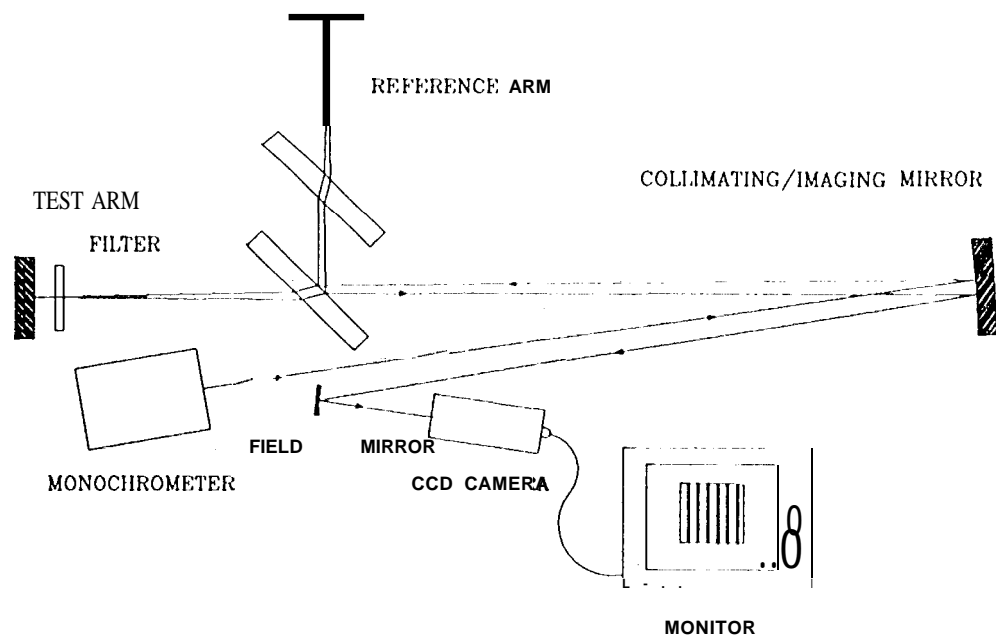


250 nm

Figure 1. Two inch interference filters



Classical Twyman-Green



Broadband Configuration

Figrrrc2.Twyrnarl-Green interferometer schematics

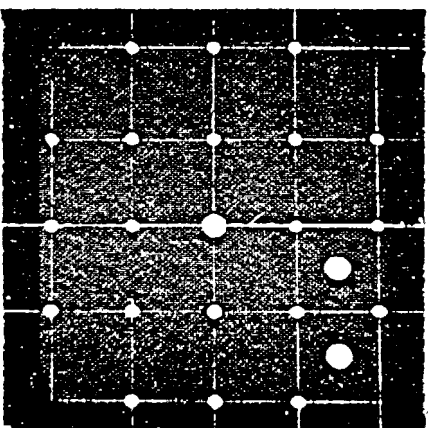
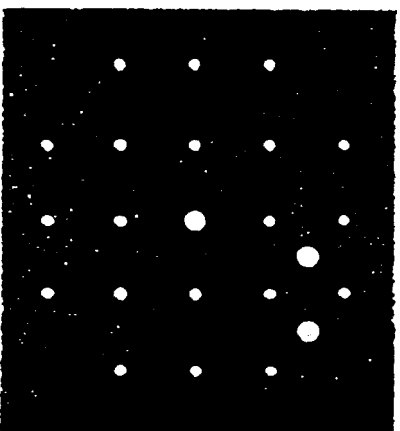


Figure Distortion test mask



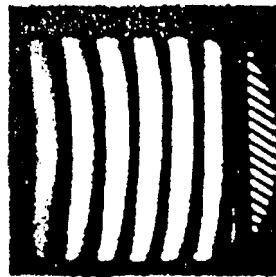
Using field lens

1

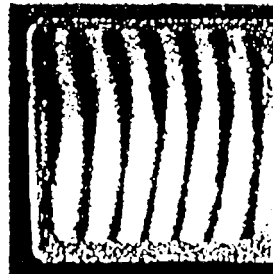


ISI field mirror

Figure Images of mask



Zygo Fizeau interferometer



Broadband Twyman-Green interferometer

Figure 5. Transmitted wavefront of high quality window @633nm

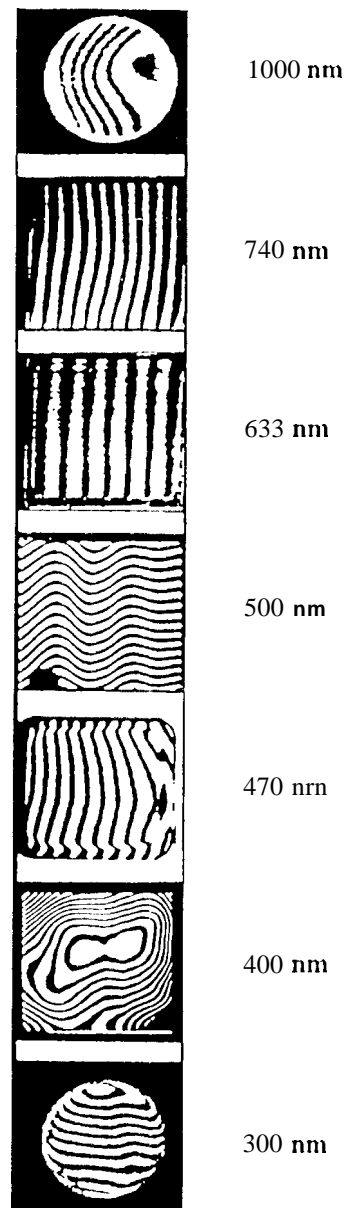


Figure 6. Transmitted wavefronts of a series of filters